Creep of Concrete with Substitution of Normal Aggregate by Recycled Concrete Aggregate

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Synopsis: This study presents the experimental results on properties of concrete with replacement of natural aggregate by recycled concrete aggregate (RCA). Experimental data on the creep behavior of concrete mixtures (basic and drying creep) was obtained. The replacement factor of natural aggregate by RCA were 0%, 15%, 30%, 60% and 100%, and the test conditions were 50% RH and 20°C. The results of these trials were used to provide a comparison with results of tests on the reference concrete, for ages up to 270 days. The creep coefficient data (instantaneous, basic and drying) presented, along with the maximum strain and the specific creep data. The results reveal considerable increase in creep when is increase replacement of natural aggregate with recycled concrete aggregate. The drying creep, especially shower more significant increase when compared to the reference concrete.

Key words: Basic creep, creep, drying creep, recycled aggregate, recycled concrete aggregate.

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INTRODUCTION

There has been little research hitherto into the long-term properties of recycled concrete aggregate (RCA). Amongst these, creep is of considerable importance if this type of aggregate is to be used for making structural concrete. Some studies with RCA indicate higher creep coefficients than are found in ordinary concrete containing natural aggregate. The creep coefficients generally tend to be 30% to 60% higher than the reference concretes mixtures. In extreme cases with total substitution of RCA for natural aggregate (NA), the creep coefficient may be up to 300% higher [1, 2, 3, 4, 5, 6, 7, 8]. In studies carried out by Sato, Kamai and Bada [9], the reported increases of creep coefficients are about 2.0, 2.2 and 3.4 times higher than with the reference concretes mixtures. According to Nishibayashi and Nishobajasi [10], it seems that these increases gradually become more marked with the passage of time.

Amongst the probable causes responsible for increase in the creep in concrete made with recycled concrete aggregate (CRCA) are low density and high porosity of the RCA, and the possibility that this type of concrete contains more free water. In addition, lower strength and lower static modulus of elasticity of this type of concrete [11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21] also contribute to high creep [22, 23, 24]. The above characteristics of RCA are attributed to the presence of old mortar adhering to surface of aggregate particles. It is known that, with ordinary concrete, the mortar matrix contributes to high strain, while natural aggregate particles tend to restricting it. Expressions have even been proposed showing the correlation between the creep phenomenon and the amount of matrix in concrete [23, 24]

In the case of CRCA, the above-mentioned premises is valid, it may be possible to estimate creep as a function of the total content of matrix in the concrete (the newly-mixed matrix plus the old matrix adhering to the natural aggregate). However, there are reports stating that creep undergoes a great increase when the aggregate (in the fine fraction of a concrete) are substituted by RCA [25]

If all the above is taken into account, the predictions and formulations of creep coefficient will need to consider these particularities in the properties both of the RCA and the concrete mixtures made with this type of aggregate (CRCA) [26]. This paper discusses what the implication might be of an increased presence of an RCA in the behavior of different of different samples of CRCA, in particular with respect to creep properties.

EXPERIMENTAL DETAILS

At this stage of our research into the creep properties of CRCA, the materials, variables, procedures and techniques were identical to those discussed in a companion paper "Shrinkage of concrete with replacement of aggregate with recycled concrete aggregate" [27]. The provisos and exceptions at this stage, which are exclusively devoted to the study of these creep properties of CRCA, are discussed in detail below.

Following the 28-day curing, two out of every four samples established for each of the ***r*** factors under study (two for basic creep and two for total creep) were coated and protected according to the specifications established in the above-mentioned study, so that these samples could then be placed inside the climatic chamber and positioned in the loading frames to begin the loading process. The samples were maintained in these environmental conditions until the end of the test period (t = 270 days)

Figure 1 shows 12 of the 24 samples used at this stage of the study. These samples were arranged in pairs and according to ***r*** factors in each one of the groups of twelve loading frames used. Figure 2 presents the details of the complete configuration for each of the loading frames used. In each frame, this configuration included a Freyssinet jack, a nitrogen gas accumulator, a manometer, a swivel for each end of the frame, a nozzle for introducing oil, and distribution plates and supports.

The beginning of the CRCA strain measurements was t_0 = 28 days of age while the established level of stress for all the concrete samples was $\sigma_c/f'_c = 0.35$. Table 1 presents the experimental values of f'_c for each ***r*** factor of the study and the level of applied stress.

Creep of Concrete Containing RCA

The strain values given below are the result of an average of the strain of two identical samples for each of the variables. To calculate the strain for basic creep ($\varepsilon_{c\ basic}$) and drying creep ($\varepsilon_{c\ drying}$), the principle of superposition of effects was applied. This considers in its calculations the instantaneous strain (ε_i) and total strain ($\varepsilon_{c\ total}$) in each case.

Similarly, the coefficients of basic creep (φ_{basic}) and drying creep (φ_{drying}), were obtained in simplified form from the creep strain (ε_c), i.e., by considering them as proportional to the instantaneous strain (ε_i) at the constant level of stress. The equation used was: $\varepsilon_c(t,t_0)=\varphi(t)\varepsilon_i(t_0)=\varphi(t)\frac{\sigma_c}{\mathbf{E(t_0)}}$. Here, $\varphi(t)$ represents the creep coefficient (relation between the stress caused by creep at a particular age and the elastic stress), σ_c = constant stress applied to the concrete and E = modulus of elasticity for the instant t_0 [18]

Finally, for the calculation of specific creep, the level of stress proposed in this experimental project was considered as being the result of $\sigma_c/f'_c = 0.35$ in each case. Then, the following equation was applied: $\textit{Specific creep} = EP/S$, with EP = total creep and $S = \sigma_c/f'_c$ stress measured in the concrete [10, 28]

Table 1 shows the instantaneous creep strain for the basic properties ($\varepsilon_{i\ basic}$) and properties associated with drying ($\varepsilon_{i\ drying}$) [27]; in both cases, these values were obtained at the moment the load was applied in the respective loading frames. These values, their variations and the limit values obtained (including those of the reference concrete) are summarized below:

1. In the case of $\varepsilon_{i\ basic}$, a maximum of 0.1645 mm/m was obtained for the factor of r = 0.30, and a minimum of 0.1350 mm/m for the factor of r = 0.15, with a variation of only 0.0295 mm/m. In this group of values, an average $\varepsilon_{i\ basic}$ of 0.1453 mm/m is calculated.

2. In the case of $\varepsilon_{i\ drying}$, a maximum of 0.1600 mm/m was obtained for the factor of r = 0.00, and a minimum of 0.1350 mm/m for the factor of r = 0.15, with a variation of only 0.0250 mm/m. In this group of values, an average $\varepsilon_{i\ drying}$ of 0.1488 mm/m is calculated.

The above results lead us to deduce that the approximations in the initial stress levels established may be considered as uniform for all the samples. This means that future validity is guaranteed in the comparison of the behavior of these samples with respect to common initial conditions and constant conditions throughout the period of study.

As for basic creep (ε_{basic}) in the CRCA samples under study, we shall say that those with a factor $r \geq 0.15$ presented overall a higher increase in strain than that obtained in the reference concrete (factor r = 0.00). Thus, it may be said that the presence of only small quantities of RCA was sufficient to alter the strain of the CRCA samples (at least with respect to ε_{basic}). Nonetheless, it is also necessary to bear in mind that the range of maximum variation obtained lies between 0.1580 mm/m for the factor r = 0.00 (t_0 = 28 days), and 0.2135 mm/m for the factor r = 0.00 (t = 270 days). This is only 0.0555 mm/m, so that it should not be considered as a parameter that would not be applicable to test concrete. The above may be seen in graphic form in Figure 1, and also in Table

2, which presents a summary of all results obtained, and calculated for the periods of 28, 90, 180 and 270 days of testing.

In the case of calculation of coefficients of basic creep (φ_{basic}) obtained on the basis of the foregoing material, it may be said that they present a tendency to rise with an increase in the factor ***r***, while the factor of concrete age is also congruent with increases in these coefficients. The above may be seen in Table 2 and in Figure 5 (specific creep), where the coefficients of φ_{basic} are presented in a solid line for the different ***r*** factors, at 28, 90, 180 and 270 days of testing. In comparative terms, and taking into account the limit values of the coefficients of φ_{basic} presented, we are speaking of increases of the order of 30% more when an CRCA with a factor of ***r*** = 1.00 is used, in comparison with the reference concrete.

As for the total creep of the CRCA samples shower in Figure 4, it may be noted that the behavior of these CRCA shower a gradual increase, where as the differences increase over the testing period, as well as with the factor ***r***. It is of particular importance to note that, beyond factors of ***r*** ≥ 0.30, the total increases in strain are considerably higher than they are below this factor.

The drying creep coefficients (φ_{drying}) of the CRCA samples (see Table 2 and the dashed lines in Figure 5 for specific creep) increase to the order of 24% in the least of cases (factor ***r*** = 0.15), and up to 47% when the factor ***r*** = 1.00. As may be seen, the proportions of increases in drying strain with variation in the ***r*** factors are considerably more marked that in the case of properties attributed to basic strain.

Finally, Figure 5 presents the behavior of CRCA samples with respect to specific creep. For variables in basic properties (solid line), it is important to note that practically all the ***r*** factors may be considered as constant for equal ages of comparison while, for variables of properties in the case of drying (dashed line), the curves are horizontal until a factor of ***r*** = 0.30, after which all the curves increase in their upward slope. This is the case almost from the very beginning of the tests through to their end.

CONCLUSIONS

Based on the results presented in this paper, the following conclusions are reached:

Specific conclusions:

1. With respect to instantaneous strain (ε_i): when the CRCA samples when submitted to equivalent levels of stress shower approximately equal strain.

2. With respect to the basic creep (ε_{basic}) of the CRCA samples studied: factors of $\boldsymbol{r} \geq 0.15$ presented overall a higher increase in strain than that obtained in the reference concrete. This suggests that the presence of small quantities of RCA in the concrete is sufficient to raise the basic creep of the concrete.

3. The coefficients of basic creep (φ_{basic}) obtained showed a tendency to rise with an increase in the ***r*** factor, while the factor of the age of the concrete is also congruent with an increase in these coefficients. These increases in the coefficients of basic creep were around 30% higher when a factor of $\boldsymbol{r} = 1.00$ was used.

4. The total creep in the CRCA shower a gradual increase, while the difference increase according to testing period time and the ***r*** factor.

5. Beyond factors of $\boldsymbol{r} \geq 0.30$, the increases in total strain were considerably higher than they are below this factor. It would seem that an RCA content below 30% was safe in the sense that this RCA content draws the line between the behavior of this types of concrete and normal aggregate concrete.

6. The coefficients of drying creep (φ_{drying}) in the CRCA samples increased to the order of 24%, and up to 47%, higher. Here, the proportions of increases in drying strain, with variation in the ***r*** factors, were considerably greater than in the case of properties attributable to basic strain.

7. The specific creep in the CRCA samples was practically constant for all ***r*** factors, while for variables of properties through drying, the curves are horizontal until a factor of $\boldsymbol{r} = 0.30$, beyond which all curves increase in their upward slope.

General conclusions:

1. The use of RCA in structural concrete mixtures is feasible if the parameters and increases in creep coefficients are correctly taken into account with respect to their behavior.

2. The development of the mechanical properties of CRCA is similar to that of ordinary concrete, although the strength levels are lower.

3. The increase in creep properties in CRCA can be explained on the basis of RCA properties.

4. The phenomenon of creep is of great importance in concrete mixtures containing RCA; the characteristics and composition of RCA affect the concrete behavior in the short and long terms. This brings about variations in the creep coefficients, therefore the use of RCA will be restricted if these coefficients are either overlooked or assumed as being identical to those of conventional concrete.

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REFERENCES

1. Environmental Council of Concrete Organizations. http://www.ecco.org

2. Hansen, T. C., and E. Bϕegh. (1995) "Elasticity and drying shrinkage of recycle-aggregate". ACI Journal, No. 5. Pp. 648 - 652, September - October.

3. Hansen, T. C. (1992) "Recycled of Demolished Concrete and Masonry". Report of Technical Committee 37-DRC Demolition and Reuse of Concrete. Part one. Pp. 1 - 160.

4. Bairagi, N. K., K. Ravande and V. K. Pareek. (1993). "Behavior of concrete with different proportions of natural and recycled

aggregates". Resources, Conservation and Recycling. Elsevier Science Publishers B.V. Vol. 9. Pp. 109 -126.

5. Sakata, K. and T. Ayano. (2000). "Improvement of concrete with recycled aggregate". CANMET/ACI. Durability of Concrete. Proceedings Fifth International Conference. Barcelona, Spain 2000. Vol. II. Pp. 1089 - 1108. Edited by V. M. Malhotra.

6. Gomez, Jose M., E. Vasquez y L. Agullo. (2001). "Strength and deformation properties of recycled aggregate concrete". Fifth CANMET/ACI International Conference on Recent Advances in Concrete Technology. Supplementary Papers. Pp. 103 - 120. Singapore. August 2001. Compiled by Venturino, M.

7. Gomez, Jose M., L. Agullo y E. Vasquez. (2001). "Physical and mechanical properties of the recycled concrete aggregates. Application in concrete". Technology and Construction. Magazine of the Mexican Institute of the Cement and the Concrete, A. C. (IMCYC). Vol. XIII, Num. 157, ISSN 0187-7895. Pp. 10 - 22. July 2001. Mexico D. F., Mexico. (In Spanish). http://www.imcyc.com/cyt/junio/cualidades.htm

8. Henrichsen, A. (2001). "Creep and shrinkage in concrete with recycled aggregate –an attempt to review the present state–of–the–art". Danish Recycled Cooperation. Dansk Beton Teknik A/S. (personal conference)

9. Sato, R., K. Kawai and Y. Baba. (2000). "Mechanical performance of reinforced recycled concrete beams". International workshop on recycled concrete. JSPS 76 Committee on Construction Materials. Pp. 127 – 146

10. Nishibayashi, S. and K. Yamura. (1988). "Mechanical properties and durability of concrete from recycled coarse aggregate prepared by chousing concrete". Demolition and Reuse of Concrete and Masonry. Vol. 2, Reuse of demolition waste. Pp. 652 - 659, November. Edited by Kasai, Y.

11. RILEM Recommendation. (1994). "121-DRG Guidance for demolition and reuse of concrete and masonry. Specifications for concrete with recycle aggregates". Materials and Structures, No. 27. Pp. 557 - 559.

12. http://www.imcyc.com/revista/1998/junio/rilem.htm

13. Fujii, T. (1988). "Strength and drying shrinkage behavior of concrete using concrete crushed aggregate". Demolition and Reuse of

Concrete and Masonry. Vol. 2, Reuse of demolition waste. Pp. 660 - 669, November. Edited by Kasai, Y.

14. Wainwright, P. J., A. Trevorrow, Y. Yu and Y. Wang. (1993). “Modifying the performance of concrete made with coarse and fine recycled concrete aggregates”. Demolition and Reuse of Concrete and Masonry, Guidelines for Demolition and Reuse of Concrete and Masonry. Pp. 319 - 330, October. Edited by Lauritzen, E. K.

15. Gómez, José M., L. Agulló and E. Vázquez. (2001). “Repercussions on concrete permeability due to recycled concrete aggregate”. Third CANMET/ACI International Symposium on Sustainable Development of Cement and Concrete. ISBN 0-87031-041-0. SP 202-13. Pp. 181-195. September 2001. San Francisco, USA. Edited by V. M. Malhotra.

16. Gomez, Jose M., L. Agullo y E. Vasquez. (2001). “Relationship between porosity and concrete properties with natural aggregate replacement by recycled concrete aggregate”. 2001 Second International Conference on Engineering Materials. ISBN 1-894662-00-8. Vol. 1. Pp. 147 - 156. August 2001. San Jose California, USA. Edited by Nagataki, S., A. Al-Manaseer and K. Sakata.

17. Gomez-Soberon, Jose M., E. Vasquez and L. Agullo. (2001). “Shrinkage and creep of recycled concrete interpreted by the porosity of their aggregate”. International Congress - Challenges of Concrete Construction. Dundee University. Scotland, RU. (Accept)

18. Gomez, Jose M., E. Vasquez and L. Agullo. (2001). “Concrete with aggregate recycled. A guideline for the material”. Monograph M60-2001. ISBN: 84-89925-80-1. Pp. 1 - 137. Barcelona, Spain. Edited by International Center of Numerical Methods in Engineering (CIMNE). (In Spanish)

19. Wainwright, P. J. and J. G. Cabrera. (1994). “Use of demolition concrete to produce durable structural concrete”. Environmental Aspects of Construction with Waste Materials. Pp. 553 - 562. Edited by Goumans, J. J. J. M., H. A. van der Sloot and Th. G., Aalbers.

20. Uchikawa, H. and S. Hanehara. (1996). “Recycling of concrete waste”. Concrete for Environment Enhancement and Protection. Pp. 163 - 172. Edited by Dhir, R. K. and T. D. Dyer.

21. Roos, F. (1998). “Verification of the dimensioning values for concrete with recycled concrete aggregate”. Uses of Recycled Concrete

Aggregate. Sustainable Construction. Pp. 309 - 319. Edited by K. Dhir, R., N. A. Henderson and M. C. Limbachiya.

22. Mark, G. A. (1996). “Aggregates and the deformation properties of concrete”. ACI Materials Journal. Pp. 569 - 577, November-December.

23. Neville, A. (1989). “Elasticity, shrinkage and creep”. Technology of the Concrete. Pp. 209 - 289. (In Spanish)

24. Neville, A. (1964). “Creep of concrete as a function of its cement paste content”. Mag. Concrete Res. 16. No. 46. Pp. 21 - 30. March.

25. Ayano, T. and K. Sakata. (2000). “Improvement of concrete with recycled aggregate”. International seminar on recycled concrete. Sponsored by Niigata University and Japan Concrete Institute (JCI) Pp. 79 – 86

26. Lopez Javier. (1996). “The new Euro-code 2 Part 1-4: Concrete of aggregate light of closed texture”. Ready Concrete, No. 27. Pp. 38 - 42, September. (In Spanish)

27. Gomez-Soberon, Jose M. V. (2001). “Shrinkage of concrete with replacement of aggregate with recycled concrete aggregate”. ACI 5th International Conference. Cancun, Mexico.

28. Smadi, Mohammad M., F. O. Slate and A. H. Nilson. (1987). “Shrinkage and creep of high, medium and low strength concretes, including overloads”. ACI Materials Journal. Pp. 224 - 234. May-June.

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Table 1 Test mixtures and conditions for the creep test.

Factor	**Test f'_c MPa**	σ_c/f'_c	**Test σ_c/f'_c MPa**	**Age of beginning of loading (t_0), (days)**	ε_c **Instantaneous basic (mm/m.)**	ε_c **Instantaneous drying (mm/m.)**
r = 1.00	34.50	0.35	12.08	28	0.1370	0.1580
r = 0.60	35.80		12.53		0.1470	0.1530
r = 0.30	37.00		12.95		0.1645	0.1380
r = 0.15	38.10		13.34		0.1350	0.1350
r = 0.00	38.80		13.58		0.1430	0.1600
OC	38.40		13.44	200	0.1180	0.1265

Note: *r* = percentage of natural aggregate replaced by recycled aggregate concrete. OC = original concrete.

Table 2 Creep of test mixtures containing recycled concrete aggregate.

Factor	Test duration (t), (days)	$\varepsilon_{c\ basic}$ (mm/m.)		$\varepsilon_{c\ drying}$ (mm/m.)		φ Coefficient		Specific creep (1/MPa)	
		Total	Basic	Total	Drying	Basic	Drying	Basic	Drying
r = 1.00	28	0.2039	0.0669	0.6054	0.3805	0.49	2.41	0.017	0.050
r = 0.60		0.2070	0.0600	0.6150	0.4020	0.41	2.63	0.017	0.049
r = 0.30		0.1950	0.0305	0.5235	0.3550	0.19	2.57	0.015	0.040
r = 0.15		0.1912	0.0562	0.5339	0.3427	0.42	2.54	0.014	0.040
r = 0.00		0.1880	0.0450	0.4947	0.2897	0.31	1.81	0.014	0.036
OC		0.3553	0.2373	0.2569	-0.1069	2.01	-0.85	0.026	0.019
r = 1.00	90	0.2539	0.1169	0.9135	0.6386	0.85	4.04	0.021	0.076
r = 0.60		0.2530	0.1060	0.8478	0.5888	0.72	3.85	0.020	0.068
r = 0.30		0.2545	0.0900	0.7320	0.5040	0.55	3.65	0.020	0.057
r = 0.15		0.2440	0.1090	0.7229	0.4789	0.81	3.55	0.018	0.054
r = 0.00		0.2062	0.0632	0.6876	0.4644	0.44	2.90	0.015	0.051
OC		0.1577	0.0397	0.3768	0.2106	0.34	1.67	0.012	0.028
r = 1.00	180	0.3066	0.1696	1.1000	0.7724	1.24	4.89	0.025	0.091
r = 0.60		0.2950	0.1480	1.0031	0.7021	1.01	4.59	0.024	0.080
r = 0.30		0.3069	0.1424	0.8780	0.5976	0.87	4.33	0.024	0.068
r = 0.15		0.3015	0.1665	0.8472	0.5457	1.23	4.04	0.023	0.064
r = 0.00		0.2579	0.1149	0.8280	0.5531	0.80	3.46	0.019	0.061
OC		0.1790	0.0610	0.4090	0.2215	0.52	1.75	0.013	0.030
r = 1.00	270	0.3505	0.2135	1.1610	0.7895	1.56	5.00	0.029	0.096
r = 0.60		0.3490	0.2020	1.0750	0.7200	1.37	4.71	0.028	0.086
r = 0.30		0.3440	0.1795	0.9480	0.6305	1.09	4.57	0.027	0.073
r = 0.15		0.3330	0.1980	0.9021	0.5691	1.47	4.22	0.025	0.068
r = 0.00		0.3010	0.1580	0.8619	0.5439	1.10	3.40	0.022	0.063
OC		0.1821	0.0641	0.4250	0.2344	0.54	1.85	0.014	0.032

Note: r = percentage of natural aggregate replaced by recycled aggregate concrete. OC = original concrete.

Figure 1 Specimens in climatic chamber.

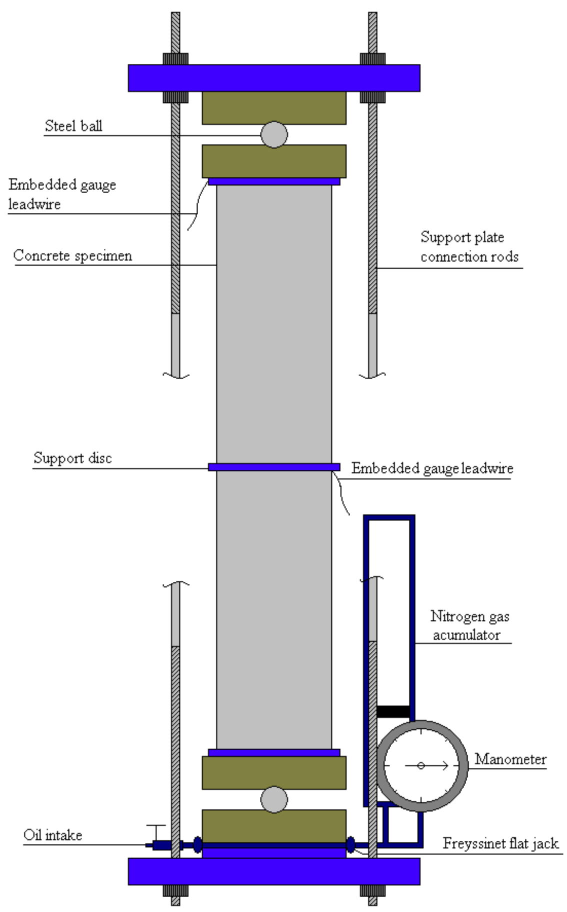

Figure 2 Supported load frame.

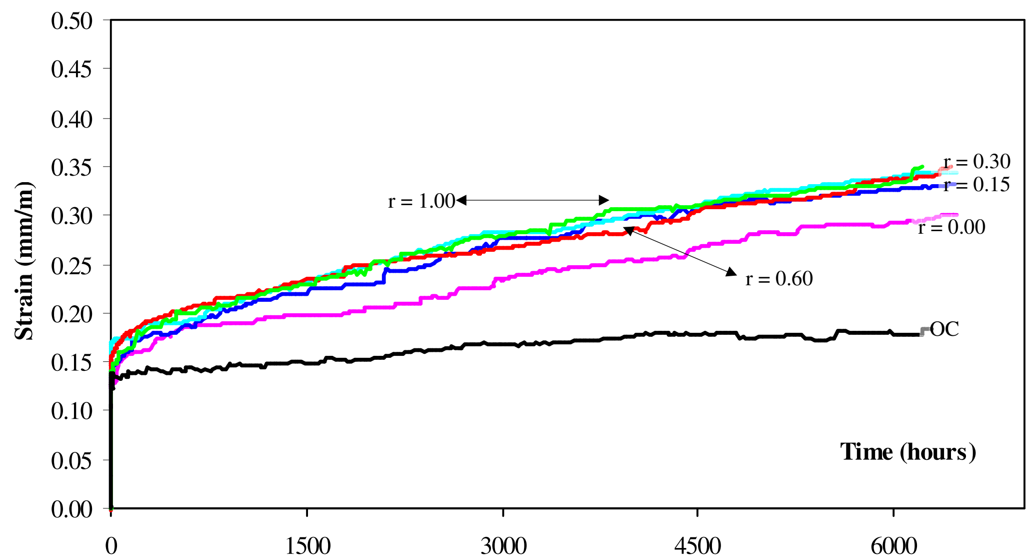

Figure 3 Basic creep for different recycled concrete.

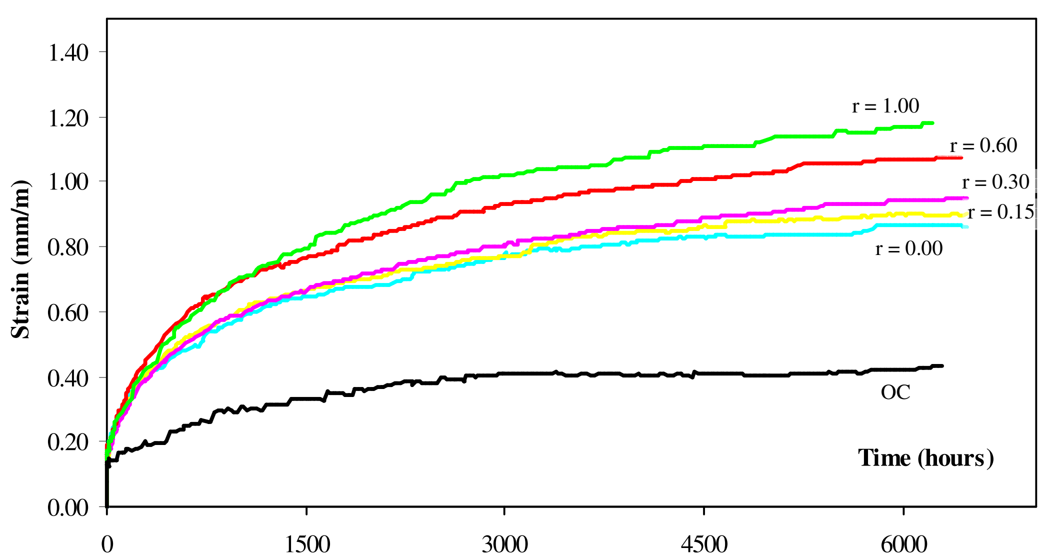

Figure 4 Total creep for different recycled concrete.

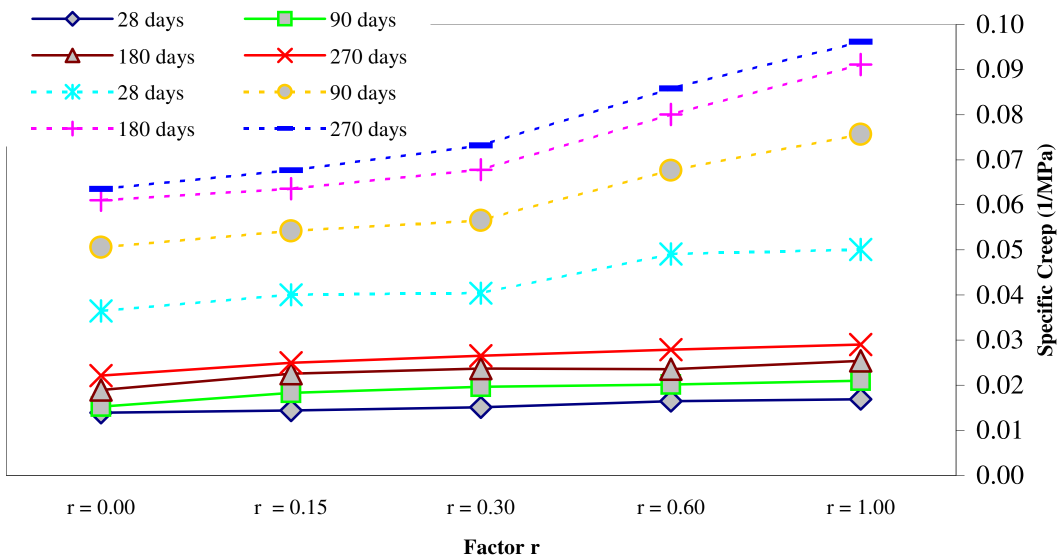

Figure 5 Specific creep for different recycled concrete.